Investigation of Interfacial Forces in CFD simulation of Turbulent Bubbly Pipe Flows

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Flow field predictions obtained by Eulerian-Eulerian Computational Fluid Dynamics (CFD) simulation of turbulent bubbly flows depend highly on the models used for the interfacial forces, that describe the interphase coupling. These models are generally developed based on theoretical and/or experimental analysis under highly simplified conditions. This work focuses on studying the effect of interfacial forces and some of the models available for their description in an air/water turbulent bubbly pipe flow. Specifically, the importance of the turbulent dispersion force on the simulation predictions will be illustrated. Moreover, the predictions obtained by employing a set of closure models for the lift and wall lubrication forces proposed for the turbulent conditions will be compared with those obtained by employing models developed under laminar conditions.
The experimental data was adopted from the work by Bayer and co-workers [1]. The setup is a vertical pipe with the inner diameter of 0.1953 (m). The air enters from the injection points located on the wall into the upward-flowing water. The flow develops gradually until it reaches a wire-mesh sensor, which performs the measurement at the top of the pipe. The simulations are performed with *twoPhaseEulerFoam* solver of OpenFOAM v4.1. It is based on the two-fluid model and it solves the governing equations using the finite volume method. Three combinations of interfacial forces are studied. Set I includes the drag force estimated by the Tomiyama's correlation; the turbulent dispersion force modelled by Burns' expression; and the lift and wall lubrication forces modelled by Tomiyama's correlation and Hosokawa's expression respectively, which are developed based on laminar experiments. Set II is the same as Set I, except that it does not include the turbulent dispersion force. Lastly, Set III is the same as Set I except that the lift and wall lubrication forces are modelled by Sugrue's correlation and Lubchenko's approach respectively, both were developed to consider turbulence conditions. The employed models are detailed in the work by Shiea et al. [2].
Figure 1 compares the predictions obtained for the air volume fraction at low (left graph) and high (right graph) inlet gas flow rate, keeping the water flow rate constant. The average bubble size is 4.25 mm and 6.0 mm respectively. In the case of smaller bubble size, Tomiyama's correlation predicts a positive lift coefficient, which leads to a lift force that pushes the bubbles toward the wall. However, it is evident, from the red and blue curves, that the lift coefficient by Tomiyama's model is too overestimated to allow the gas phase to spread toward the pipe center. Moreover, the comparison of the blue and red curves shows that the addition of the turbulent dispersion force changes the results negligibly. On the other hand, the prediction obtained by Set III (green curve) agrees better with the experiments, although the peak near the wall is damped, which suggests that the Sugrue's model underestimates the lift coefficient.
In the case of larger bubble size (right plot), the effect of the turbulent dispersion force is considerable (by comparing the blue and red curves) as it helps the gas phase to spread in the radial direction. Another notable point is that the predictions obtained by using Hosokawa model show a zone without gas phase near the wall, inconsistent with the experiments. In other words, the wall lubrication force by Hosokawa is exceedingly strong near the wall, particularly for large bubbles, whereas the Lubchenko's approach provides a more reasonable wall lubrication force.
These findings highlight the necessity of studying interfacial forces under turbulent conditions for developing models and evaluating their performance.

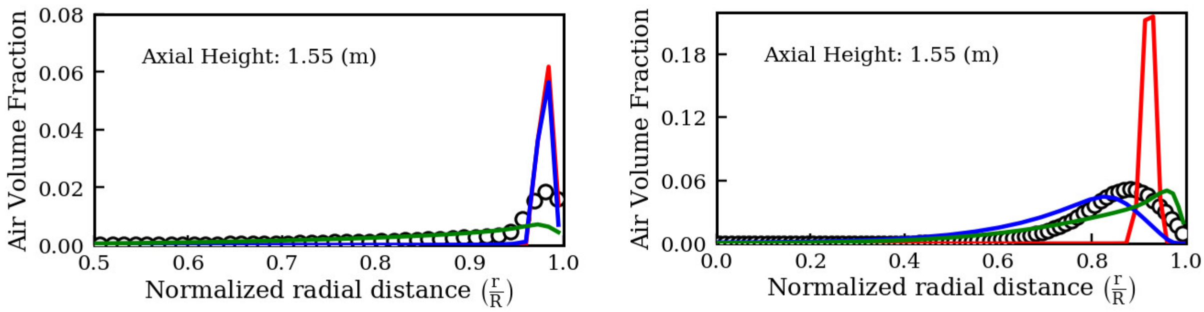

Figure 1. The predicted radial profiles of volume fraction versus the experiments. Hollow markers: experimental measurements; red curve) Set I; blue curve) Set II; green curve) Set III

References

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